AØ RF-Gun Cooling System

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Abstract- The AØ Photoinjector (AØPI) consists of a Radio Frequency Electron Gun (RF-gun) that essentially accelerates a beam of electrons. The RF-gun is cooled by a low-conductivity water (LCW) skid cooling system. The performance of LCW systems is of critical importance at accelerator facilities [10]. An imbalance of water chemistry, supply temperature, or component availability can have a direct impact on the machine's performance [10]. DESY, a high-energy physics laboratory in Germany, will soon install a new RF-gun in the north cave of the AØPI facility that will require the same cooling as the current RF-gun, which is located in the south cave of AØ. Before installation occurs, it must be assured that the current cooling system for the AØPI RF-gun is up to par. We investigate how the AØPI RF-gun skid system was characterized, improved, and documented over the course of a summer.

NOMENCLATURE:

d = internal diameter of pipe (in)

D = internal diameter of pipe (ft)

f = friction factor

g = acceleration of gravity (ft/s^2)

h_L = head loss (ft)

K = resistance coefficient

L = length of pipe (ft)

μ = absolute viscosity (cP)

P_1 = starting pressure (psi)

P_2 = ending pressure (psi)

ΔP = change in pressure (psi)

ΔP_T = change in total pressure (psi)

Q = rate of flow (gpm)

ρ = weight density (lb/ft^3)

v = mean velocity of flow (ft/s)

Z_1 = lowest elevation (ft)

Z_2 = highest elevation (ft)

I. INTRODUCTION

i. Fermi National Accelerator Laboratory

President Lyndon B. Johnson signed a bill on November 21, 1967 commissioned by the United States Atomic Energy Commission for the National Accelerator Laboratory. Seven years later on May 11th, the laboratory was renamed Fermi National Accelerator Laboratory (Fermilab or FNAL) in honor of Enrico Fermi a 1938 Nobel Prize winner and preeminent physicist. As part of the Department of Energy's strategic goals, the mission of the laboratory became to advance the understanding of the fundamental nature of matter and energy by providing leadership and resources for qualified researchers to conduct basic research at the frontiers of high energy physics and related disciplines. Presently, the laboratory is approximately 6,800 acres and located in Batavia, Illinois. Also, it is home to the world's highest-energy particle accelerator. [1]

ii. AØ Experiment

Fermilab is comprised of many different divisions. The project discussed in this report was conducted in the Accelerator Division (AD). The AØ Photoinjector (AØPI) facility is a small research and development program section within the AD. This department is located in a building referred to as the A Zero (AØ) building. An essential component of the overall AØPI is a Radio Frequency Electron Gun (RF-gun). The RF-gun is located in the laser room which is in the south cave of the AØ building. This gun consists of cavities that are used to accelerate a beam of electrons.

iii. Project

As the RF-gun runs, it gives off heat. This poses as a problem both to the well-being of the machine as well as the physicists. If the machine becomes too hot, it could damage its manufactured restraints. Physicists would like for the gun to maintain a steady temperature in order for them to perform accurate tests. Therefore, engineers of the Mechanical Support Department created a low-conductivity water (LCW) skid cooling system that would keep the RF-gun from overheating by keeping it at a consistent temperature.

Within the next 5 years, a new RF-gun from Deutches Elektronen Synchroton (DESY), a high-energy physics laboratory in Hamburg, Germany, will be installed in the AØ north cave. The new RF-gun will use the same cooling system as the current gun, but before the installation occurs it must be assured that the current cooling system for the AØ PI RF-gun is up to par. This paper investigates how the AØ PI RF-gun skid system was characterized, improved, and documented over the course of a summer. In order to obtain these goals the following steps had to be executed:

- Outlined spreadsheet acting as a project timeline (for organization purposes),
- Development of a detailed system schematic,
- Refinement of the system's appearance,
- Completed fluid analysis throughout system by calculating pressure changes.

iv. Background

During the early 1990's when Fermilab conceived the extensive photoinjector research and development program [1], Fermilab mechanical engineer, John Satti set out to develop the skid system. The original skid design for the AØ RF-gun interlocked three skids. Skid #1 was a glycol-water chiller. This skid acted as a cooling unit that provided chilled glycol to heat exchange with skid #2. Skid #2 was a low-conductivity water (LCW) skid system that received processed water, sent it through the heat exchanger, and pumped it to skid #3. This skid contained the de-ionizing loop. Skid #3 was a skid using another heat exchanger to assist with power supplies and klystron cooling. In 2004, skid #3 was transported to the New Muon Lab (NML) service building for use as a temperature cooling skid for their LCW system. James Santucci was then heading the AØPI facility and complied that skid #3 would no longer be needed for his project. Today the AØ RF-gun cooling system still consists of the two skids, a glycol chiller and a LCW skid.

II. METHODS

i. Instrumentation

Microsoft Visio

Microsoft Visio is a diagramming program for Microsoft Windows that uses vector graphics to create diagrams [3]. Once the program is opened, you are welcomed by Getting Started with Microsoft Office Visio screen and prompted to select the kind of template that you wish to use (Figure 1). Once a template is selected, you may then be taken to a sub-category page. Upon your selection you will be given a grid-lined blank canvas (Figure 2). On the left-hand side of the screen there is a column labeled **Shapes** with many different sections of shape types. This tab will vary based on the template chosen. For the AØ RF-gun cooling system schematics, the path of choice was **Engineering** > **Process Flow Diagram**. This then led the shape sections under the **Shape** column to include: Equipment (General), Heat Exchangers, Pumps, Vessels, Instruments, Pipelines, Process Annotations, and Valves and Fittings. For development of the project manager file, the path was **Schedule** > **Gantt Chart**. An example of a Schedule type document in Microsoft Office Visio is shown in Figure 3.

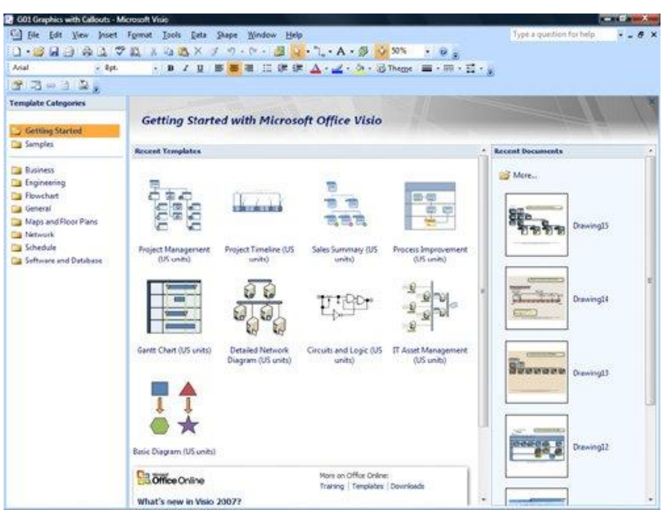

Figure 1. Getting Started with Microsoft Office Visio 2007 welcome screen

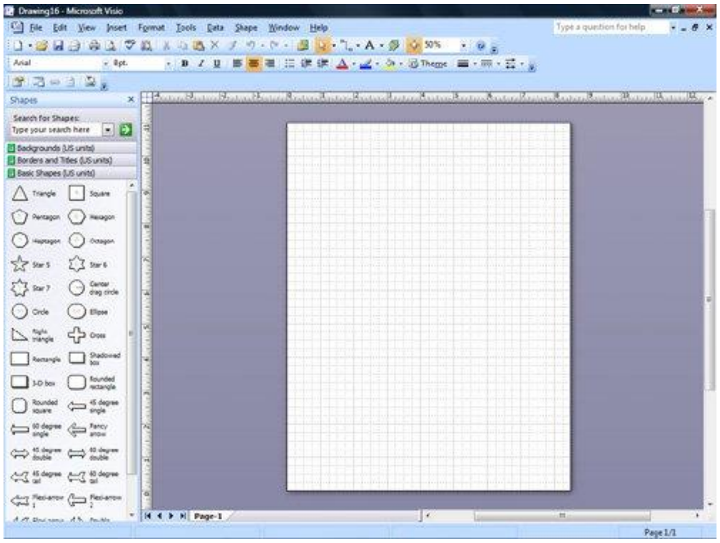

Figure 2. Microsoft Office Visio2007 grid-lined blank canvas

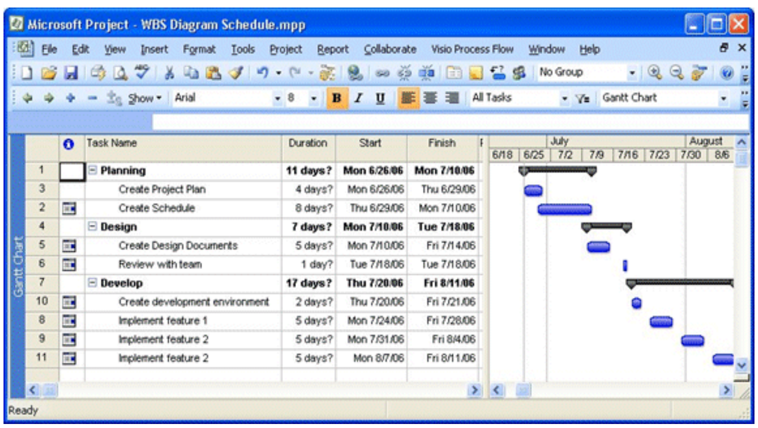

Figure 3. Sample image of a Schedule type document in Microsoft Office Visio 2007

PT878 Ultrasonic Flowmeter

GE Panametrics manufactured an instrument called PT878 Portable Liquid Flowmeter, also referred to as the TransPort® Model PT878 (Figure 4). The PT878 is a transit-time ultrasonic flowmeter that combines all the features of a full-size flowmeter with the advantages of a portable instrument. The PT878 is one part of the flowmeter system. The flowmeter system consists of two essential subsystems: the flowcell and the electronics package (the PT878). The flowcell is the part of the system that uses ultrasonic pulses to interrogate the flow. It consists of the flowcell pipe and the transducers. The goal of the flowcell piping is to provide mechanical support for the transducers and assure stable fluid conditions for accurate flow measurement. The transducers convert electrical energy into ultrasonic pulses when in a transmit cycle, and convert the ultrasonic pulses back to electrical energy when in a receive cycle. The electronics package (the PT878) consists of circuits that generate, receive, and measure the travel time of the ultrasonic pulses. It also contains a microcomputer that controls operation and calculates flow measurement parameters. Specific circuits include: transmit signal generator, transmitter, receiver, data acquisition, timing circuit, microcomputer, and input/output.

During operation, two transducers serve as both ultrasonic signal generators and receivers. When mounted on a pipe, they are in acoustic communication with each other, so that each transducer can receive ultrasonic signals transmitted by the other transducer. Each transducer thus functions as a transmitter generating a certain number of acoustic pulses, and as a receiver for an identical number of pulses. The flowmeter measures the time interval between transmission and reception of the ultrasonic signals in both directions. [4]

Figure 4. An image of a GE Panametrics PT878 Portable Liquid Flowmeter

III. RESULTS

i. System Schematic

The first task that I was assigned was to re-create a schematic using Microsoft Office Visio 2007. The original schematic was in two parts. Those parts were labeled HINS-ILCTA MESON LCW SKID and HINS LCW Connections for Ion Source Cage Radio Frequency Quadrupole (RFQ) Interlock Test Setup respectively. Once this task was completed, as shown in Diagram 1 of the Appendix, permission was granted for the launch of the AØ RF-gun skid system schematic.

Upon completion of one thorough walk-through of the AØ RF-gun skid system, the system schematic began to take form. Because the system is so large, it was decided to break the schematic into two separate documents. The first document would be for the system outline, and the second document would detail the system skids.

The first draft of each schematic (Diagram 2a and Diagram 2b) did not meet the expected standards. The main problems with these drafts were as follows:

- The lines were too bold,
- The documents were three-dimensional,
- There were missing valves and gauges,
- There was no sense of pipe length or pipe size,
- There was no reference as to where the pipes were located in AØ.

These issues were resolved as the draft numbers increased. Subtle progressive changes occurred with each draft.

On the RF-Gun System schematic, the entire layout of the document was remodeled on Draft #3. The AØ Control Room, North Garage, and North Cave were shown on the document. Also, the system branch-offs were labeled. After five drafts had been completed, all valves and gauges were shown and the gauges had been re-labeled. Diagram 3a and Diagram 3b show the original gauge labeling over the system, and Diagram 4a and Diagram 4b show the upgraded labeling. The original gauge labeling was incomplete and repetitive. The upgrade labels the entire system 1- 18. On Draft #6 pipe sizes were added, and the schematic was completed on Draft #7 (shown in Diagram 5a).

Draft #4 of the Process LCW and Chiller Glycol Skids for RF-Gun schematic introduced and perfected the de-ionizing loop. Upon completion of Draft #6, all valves and gauges (local and remote) had been added, and the system had been re-labeled. Again, Diagram 3b shows the original labeling and Diagram 4b shows the upgrade. Pipe sizes and tank levels were added on Draft #7 to complete the schematic (shown in Diagram 5b).

These schematics served as an essential helping-hand for fluid analysis.

ii. Fluid Analysis

Before a new RF-gun can be added to the AØ facility, it is imperative that the present system be fully operational and effective. For this reason, pressure drop calculations were conducted throughout the system. First, all of the present pressure and temperature gauge readings were documented using an Excel® spreadsheet (shown in Table 1); these readings will later be used to compare with the calculated pressure drop.

In 1738 Daniel Bernoulli derived an equation that is now the most useful single equation in fluid mechanics [6, 7]. His theorem is a means of expressing the application of the law of conservation of energy to the flow of fluids in a conduit [3].

$$Z_1 + \frac{144P_1}{\rho_1} + \frac{v_1^2}{2g} = Z_2 + \frac{144P_2}{\rho_2} + \frac{v_2^2}{2g} + h_L \qquad \text{Equation 1}$$

According to Bernoulli's equation (Equation 1), the pressure drop between P_1 and P_2 can be expressed as:

$$P_1 - P_2 = \frac{\rho}{144}\left((Z_2 - Z_1) + \frac{v_2^2 - v_1^2}{2g} + h_L \right) \qquad \text{Equation 2}$$

In order to calculate the change in pressure, according to Equation 2, there are other equations needed:

$$h_L = \frac{0.00259KQ^2}{d^4} \qquad \text{Equation 3}$$

$$K = f\frac{L}{D} \qquad \text{Equation 4}$$

$$R_e = \frac{50.6Q\rho}{d\mu} \qquad \text{Equation 5}$$

In efforts to minimize calculation errors, the entire cooling system was separated into 13 individual sections, labeled A-M; these sections are color coordinated in Diagram 6a and Diagram 6b. Each section's length (L), elevation changes (Z_1 and Z_2), and rate of flow (Q) had to be measured. While a basic tape measurer was used for L and Z, a GE TransPort® PT878 ultrasonic flowmeter, programmed for this system, was used to obtain reliable readings for Q. Four sections, each about 1½ feet long, along the system were chosen for measurement collection. These sections were chosen because they are each located where some flow is lost, shown in Figure 5. For the first section the volume read steady at 30.0gpm. The second section read the flow rate to be 24.4gpm. The third section measured 5.5gpm and the fourth, 4.85gpm. Following measurements, standard tables found in Crane's Flow of Fluids book, were used to find the values for f_T, μ, ρ, and v of each section (A-M). Upon assuming that all fitting were standard 45˚ or 90˚ elbows, calculations began.

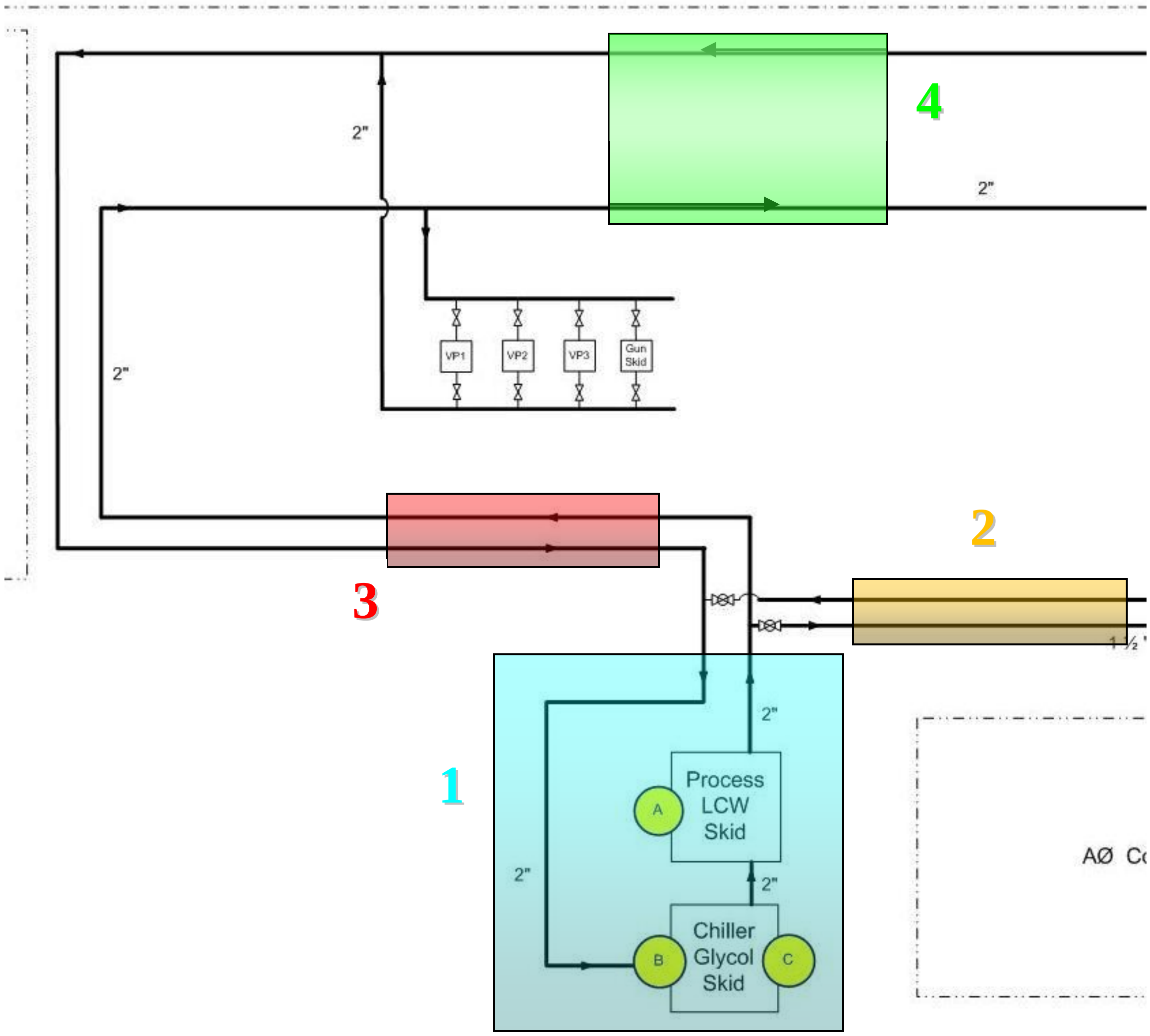

Figure 5. Focuses on the four separate sections that were used to measure rate of flow on the AØ RF-gun cooling system for a better understanding of the Q value outcomes.

Section A:

Given:

$d = 0.17225$ ft

$f_T = 0.019$

$\mu = 1.7$ cP

$\rho = 62.42$ lb/ft^3

$v = 2.87$ ft/s

Measurements:

$Z_2 = 9.833$ ft

$Z_1 = 0$ ft

$L = 69.5$ ft

$Q = 30$ gpm

Calculations:

$$R_e = \frac{50.6}{2.067in} \times \frac{30gal}{min} \times \frac{62.42lb}{ft^3} \times \frac{1}{1.7cP} = \frac{94753.6}{3.5139} = 2.7 \times 10^4$$

f = 0.026 (see page **A-18**)

$$K = \frac{0.026 \times 69.5ft \times 12in}{2.067in \times ft} = \frac{21.684}{2.067} = 10.49$$

45˚ elbow = 16 $f_T \gg 2 \times 16 \times 0.019 = 0.608$
90˚ elbow = 30 $f_T \gg 12 \times 30 \times 0.019 = 6.84$

$$K_{TOTAL} = 0.608 + 6.84 + 10.49 = 17.95$$

$$h_L = \frac{0.00259 \times 17.95 \times 30^2}{2.067^4} = \frac{41.84}{18.254} = 2.292\ ft$$

$$\Delta P = \frac{62.42lb \times ft^3}{144in^2 \times ft^3}(9.833\ ft + 0\ ft + 2.292\ ft) = 5.256\ psi$$

The same calculations were conducted for sections B-M, with some variable value changes. Length and elevation values routinely changed with each section. Other occasional variable changes included d, Q, v, and ρ. The pressure change results for each section is as follows: A = 5.256psi, B = 1.664psi, C = 0.893psi, D = 2.484psi, E = 1.398psi, F = 1.061psi, G = 5.174psi, H = 1.423psi, I = 1.134psi, J = 4.213psi, K = 4.444psi, L = 5.561psi and M = 3.909psi.

$$\Delta P_T = Section\ A + Section\ B + \ldots + Section\ L + Section\ M$$

Equation 6

The entire system's calculated pressure drop, according to Equation 6, is then 38.614psi. By reading the highest reading on the pressure gauge and subtracting it from the lowest reading, on Table 1, we find that the system calculated overall pressure drop is 135psi. This creates a different of 96.386psi.

IV. CONCLUSION

In summary, the goals of this project were executed. The system schematic created using Microsoft Office Visio 2007 was perfected. The pressure and temperature gauges were all successfully re-labeled and documented using a Microsoft Office Excel spreadsheet. Flow rate was measured for calculation purposes, and also served to present an updated reading for the system. Pressure drop throughout the entire system was calculated, and a project manager, also created using Microsoft Office Visio 2007, was established. These conclusions show that, as hypothesized, the current cooling system for the AØ RF-gun is not properly functioning.

V. ACKNOWLEDGEMENTS

I would like to provide sincere gratitude towards both of my supervisors this summer, Maurice Ball and James Santucci. I give special appreciation to my mentors here at Fermilab, Elmie Peoples-Evans and David Peterson. Within the Accelerator Division, I will direct my attention to thank the AØ facility and the Mechanical Support Department (MSD). The co-op students working in MSD were very welcoming and sincere with counsel. Of course this wonderful experience could not have come had it not been for the Summer Internships in Science and Technology (SIST) program. Dianne Engram, Dr. James Davenport, Linda Diepholz, and Jamison Olsen all made this year's program successful. I also thank the staff, committee, and fellow 2009 interns that were a part of the SIST program this year. Finally I give thanks to my largest support team, my family.

VI. APPENDIX

AØ RF Gun Skid System gauge readings

Pressure Gauge	psi	Temperature Gauge	°F
P-01	33	T-01	53
P-02	13	T-02	36
P-03	7.5	T-03	51
P-04	62.5	T-04	50.5
P-05	9	T-05	65
P-06	7	T-06	45
P-07	140	T-07	60
P-08	137	T-08	58
P-09	19	T-09	44
P-10	9.5	T-10	82
P-11	5		
P-12	141		
P-13	135		
P-14	10		
P-15	54		
P-16	10		
P-17	22		
P-18	25		
P-19	22		

Table 1: Displays the actual readings shown on all the pressure and temperature gauges on the AØ RF-gun skid system, as of June 2009.

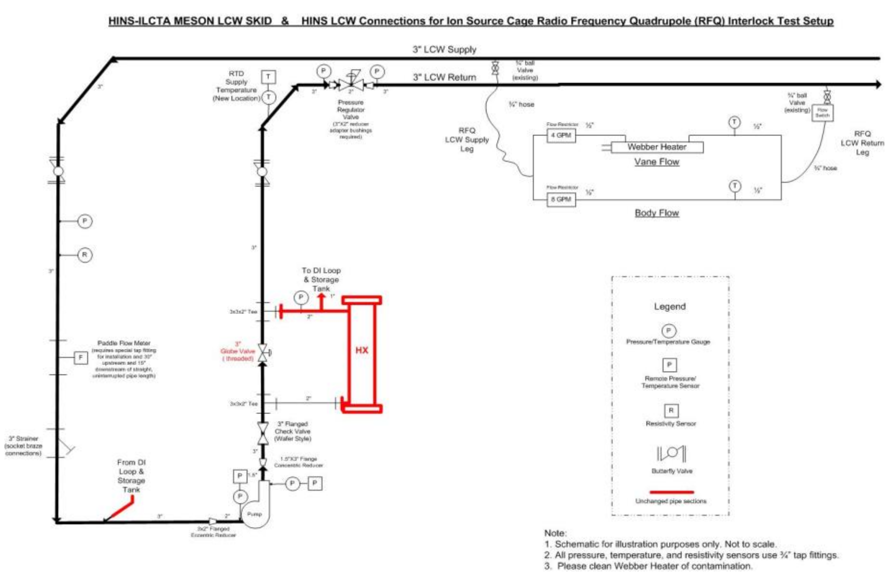

Diagram 1: Combination of a HINS-ILCTA Meson LCW Skid schematic and a HINS LCW Connections for Ion Source Cage Radio Frequency Quadrupole (RFQ) Interlock Test Setup schematic.

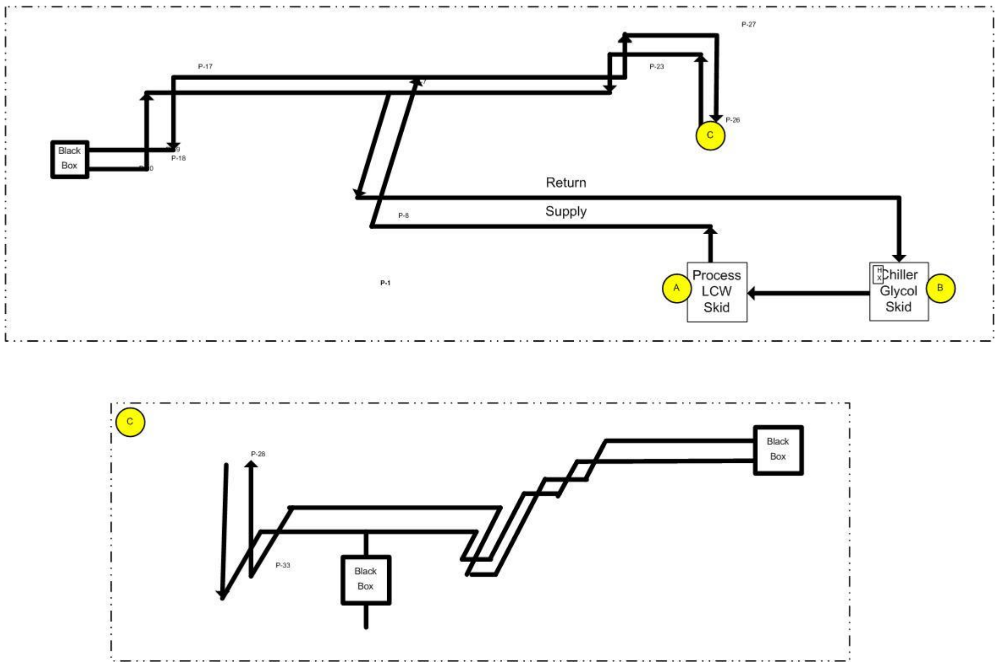

Diagram 2a: Draft #1 of the AØ RF-Gun Skid System Outline schematic.

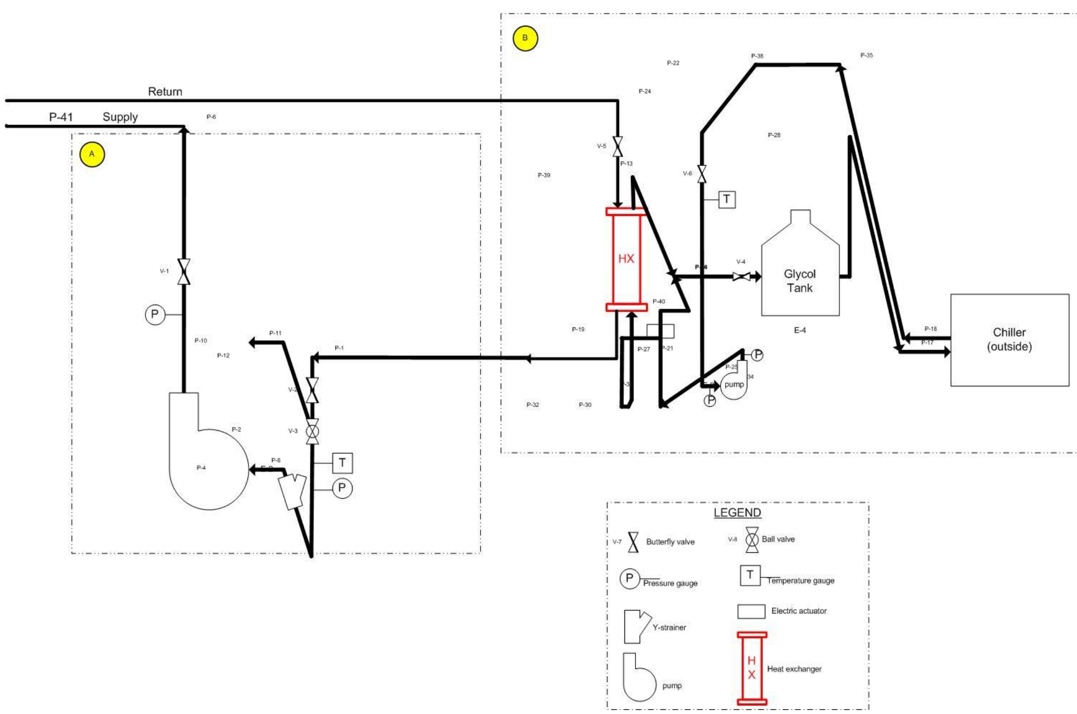

Diagram 2b: Draft#1 of the Process LCW and Chiller Glycol Skids for RF-Gun schematic.

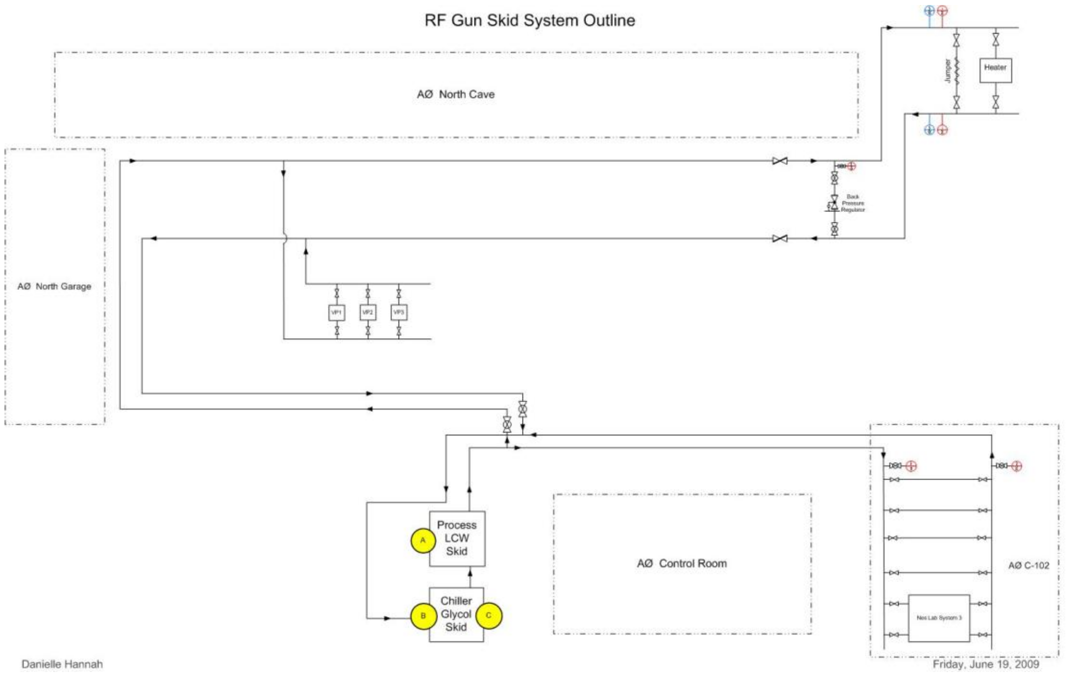

Diagram 3a: Focuses on the aØ RF-Gun Skid System Outline schematic before the pressure and temperature gauges were re-labeled.

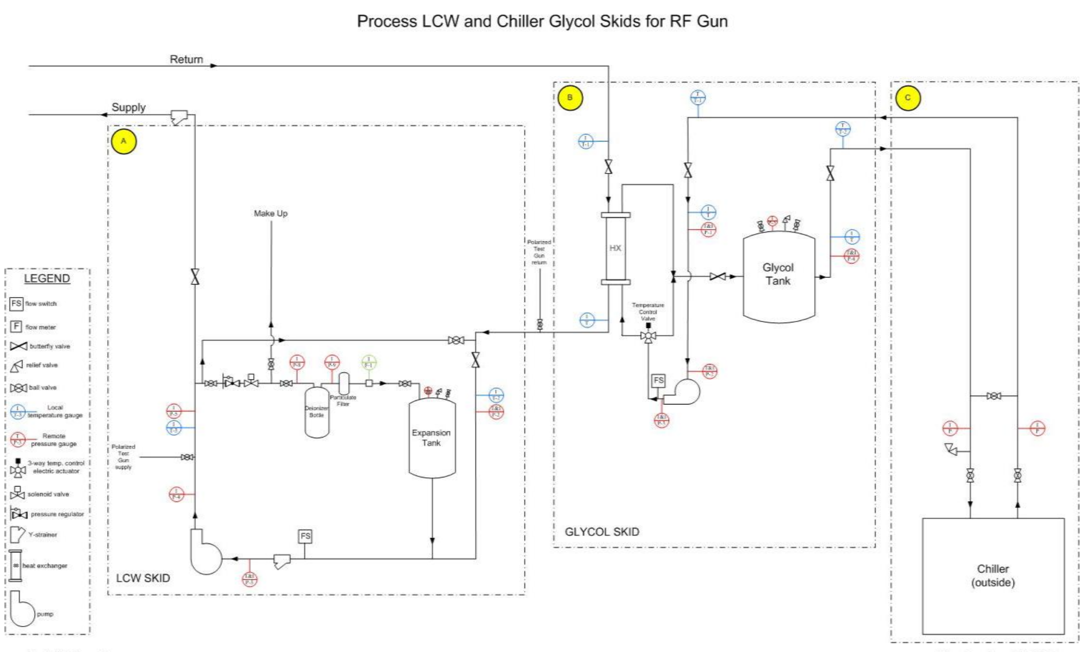

Diagram 3b: Focuses on the Process LCW and Chiller Glycol Skids for RF-Gun schematic before the pressure and temperature gauges had been re-labeled

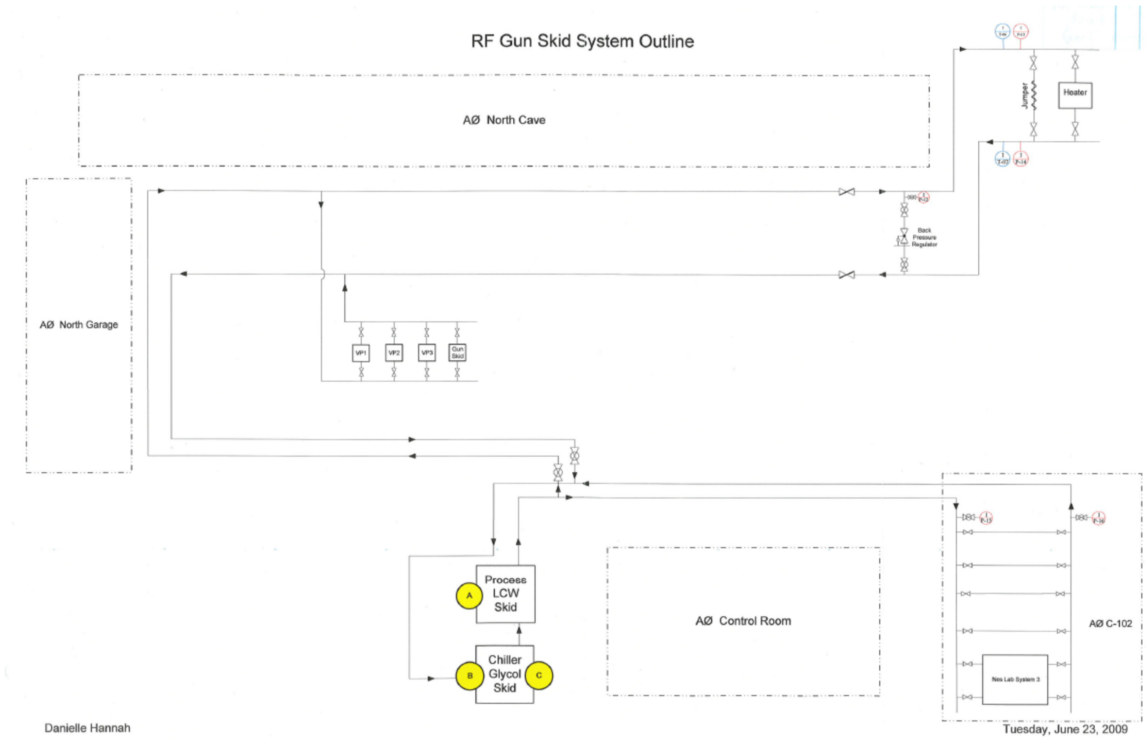

Diagram 4a: The RF Gun Skid System Outline schematic with the re-labeled pressure and temperature gauges shown.

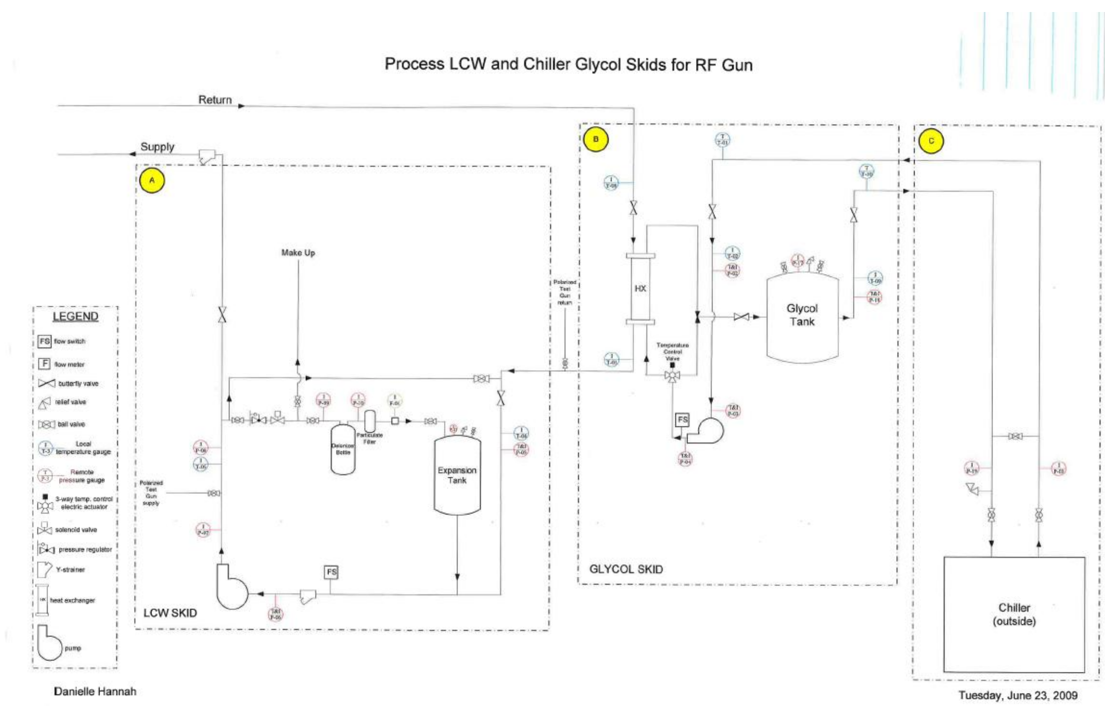

Diagram 4b: The Process LCW and Chiller Glycol Skids for RF-Gun schematic showing the re-labeled pressure and temperature gauges.

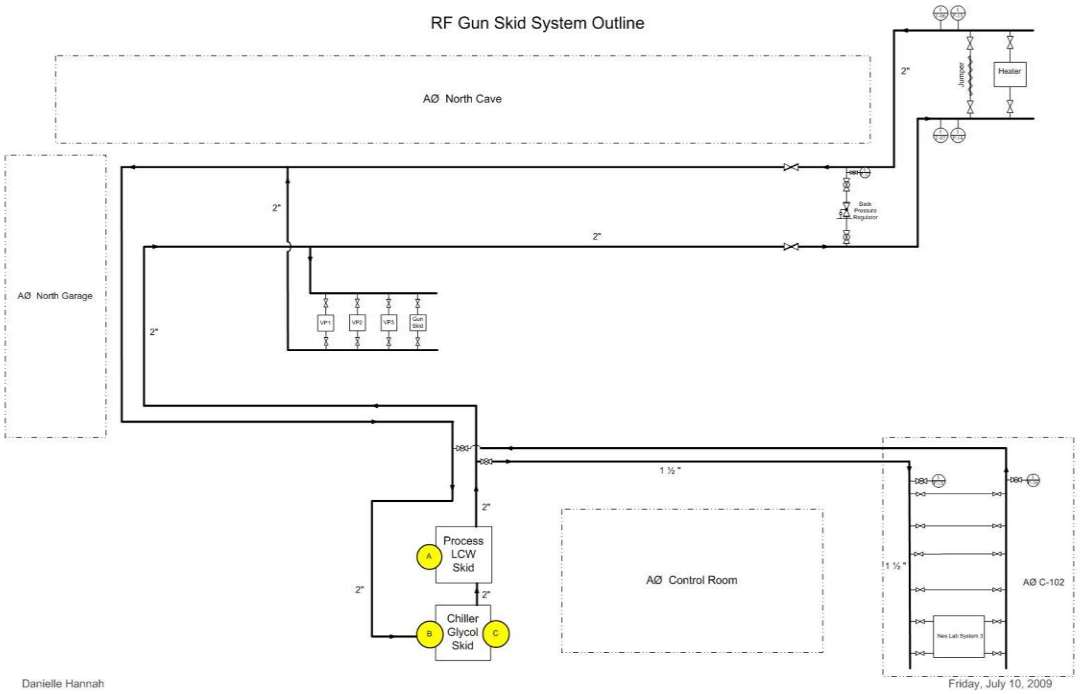

Diagram 5a: The final draft of the RF Gun Skid System Outline schematic.

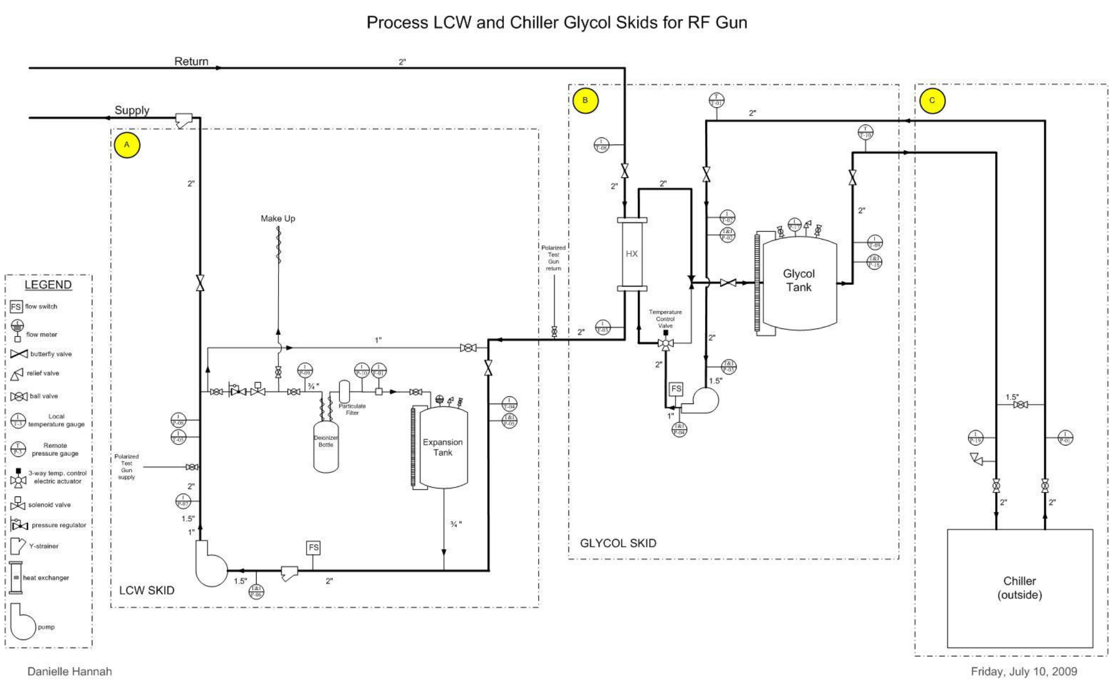

Diagram 5b: The final draft of the Process LCW and Chiller Glycol Skids for the RF-Gun schematic.

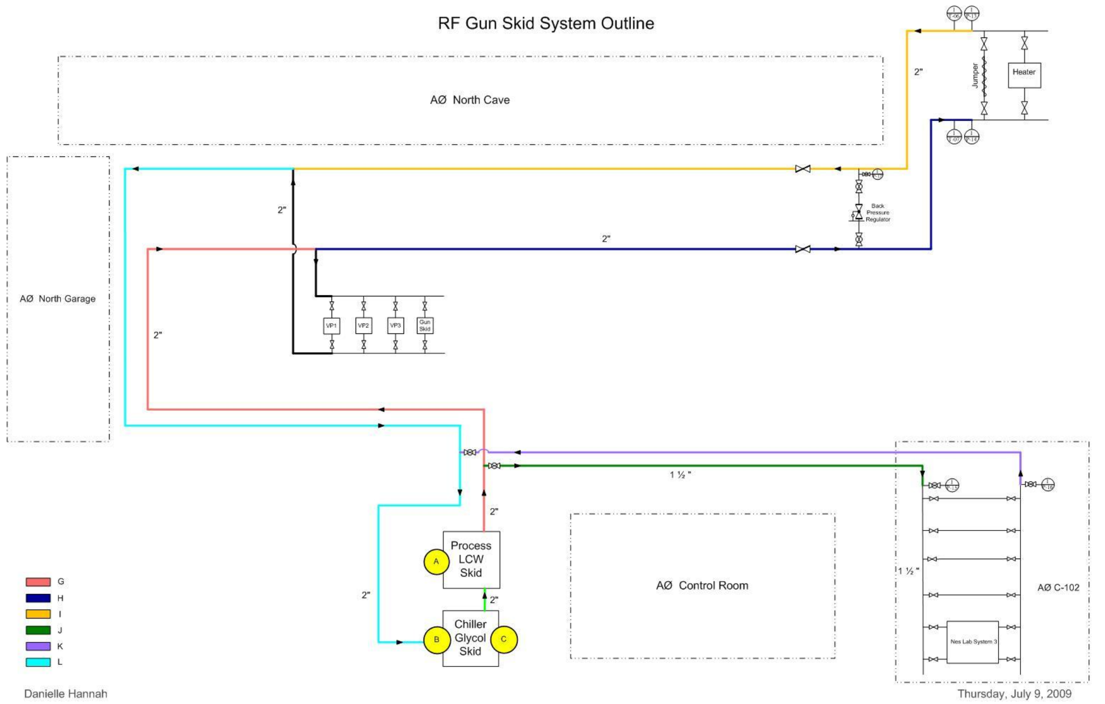

Diagram 6a: The RF-Gun Skid System Outline schematic color coordinated to show Section G through Section L.

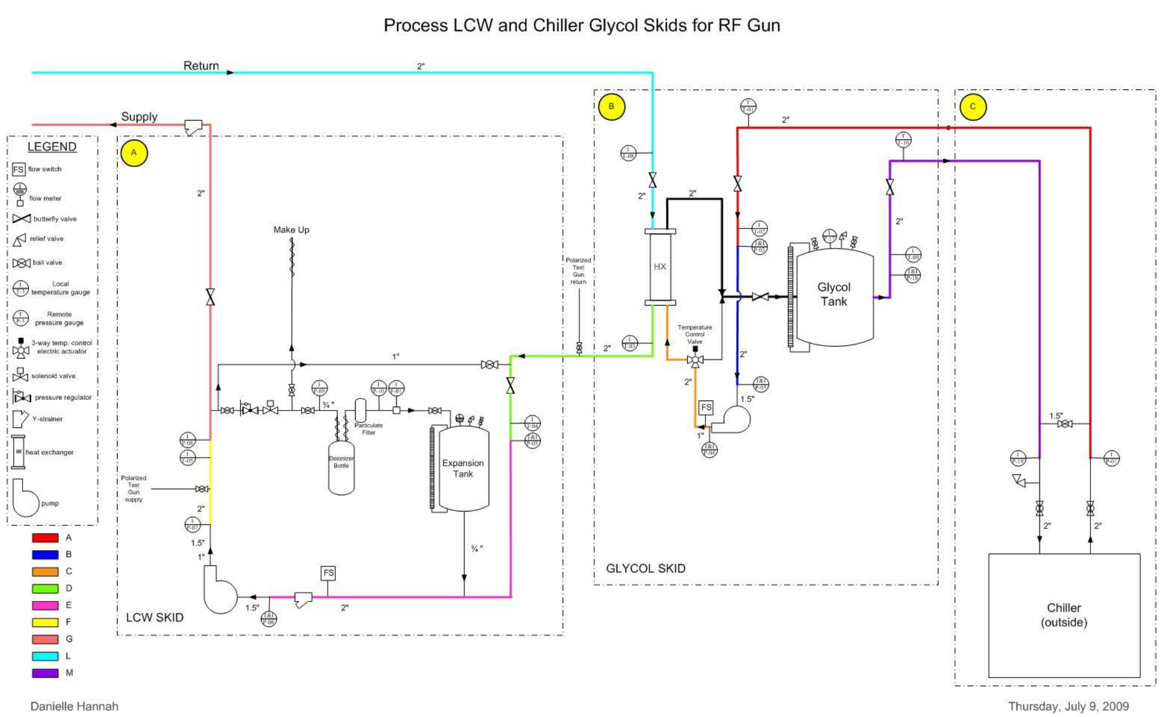

Diagram 6b: Process LCW and Chiller Glycol Skids for RF-Gun schematic color coordinated to highlight Section A-Section G, Section L-Section M.

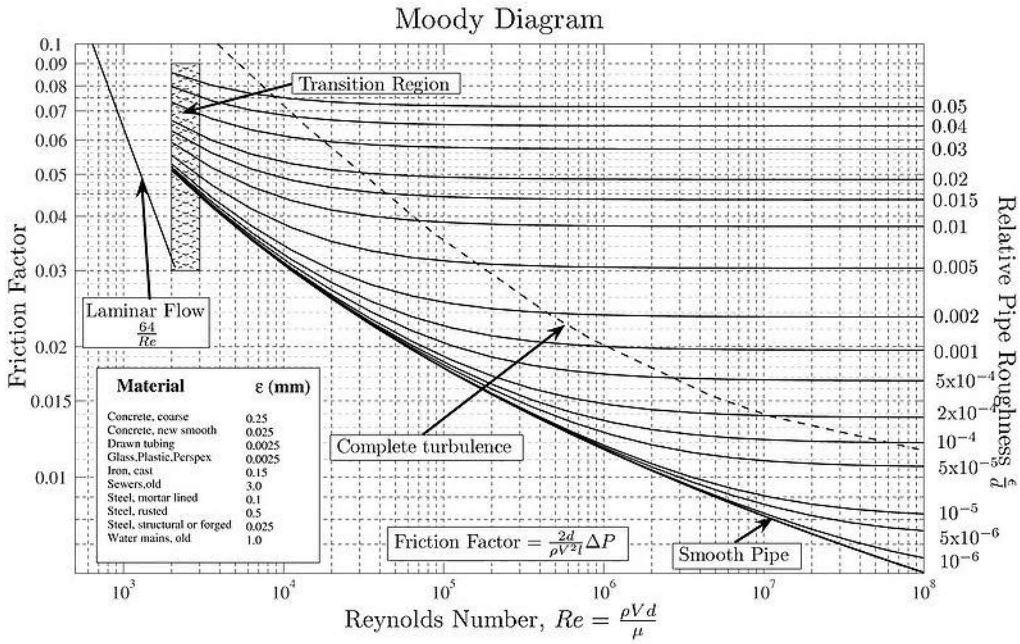

Chart 1: Moody Chart used to find the friction factor (*f*).

VII. REFERENCES

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